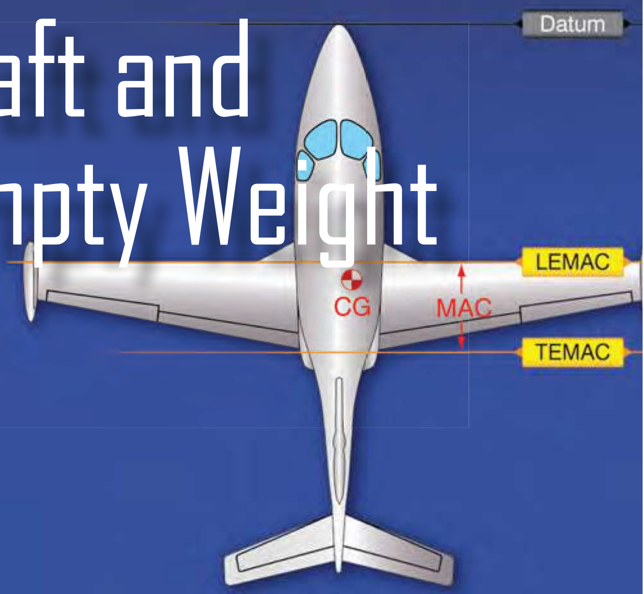
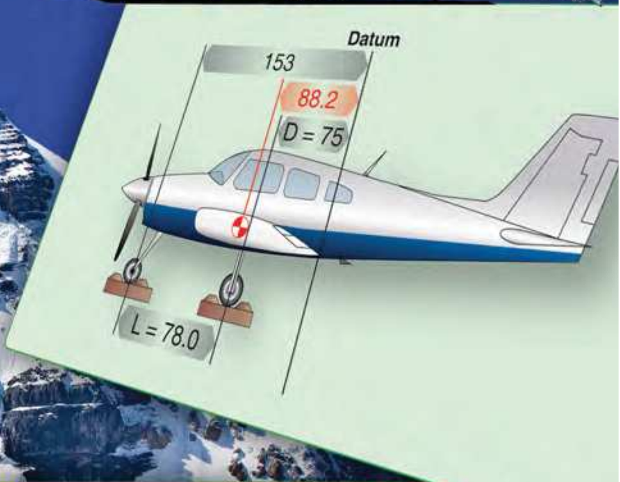
Chapter 3

Weighing the Aircraft and Determining the Empty Weight Center of Gravity



Introduction

Chapter 2, Weight and Balance Theory, explained the theory of weight and balance and gave examples of the way the center of gravity (CG) could be found for a lever loaded with several weights. In this chapter, the practical aspects of weighing an airplane and locating its CG are discussed. Formulas are introduced that allow the CG location to be measured in inches from various datum locations and in percentage of the mean aerodynamic chord (MAC).



$$\text{CG inches from datum} = \text{LEMAC} + \frac{\text{MAC} \times \text{CG \% MAC}}{100}$$
$$= 144 + \frac{62 \times 27.4}{100}$$
$$= 160.9$$

$$\text{CG} = \frac{\text{Total moment}}{\text{Total weight}}$$
$$= \frac{65{,}756}{2{,}006}$$
$$= 32.8 \text{ inches behind the datum}$$

Weighing point	Scale reading (lb)	Net weight (lb)	Net weight (lb)	Arm (inches)	Moment (lb-in)	CG
Right side	846	16	830	46.0	38,180	
Left side	852	16	836	46.0	38,456	
Nose	348	8	340	−32.0	−10,880	
Total			2,006		65,756	32.8

Requirements

Regulations do not require periodic weighing of privately owned and operated aircraft. Such aircraft are usually weighed when originally certificated or after major alterations that can affect the weight and balance. The primary purpose of aircraft weight and balance control is safety. Manufacturers conduct extensive flight tests to establish loading limits for their aircraft because limit information is critical for safe flight. A secondary purpose is to aid efficiency during flight. Overloading of the aircraft is not the only concern; the distribution of the weight is important also. The aircraft has CG limits, and any loading that places the CG outside the established limits seriously impairs controllability of the aircraft.

Weight and balance is of such vital importance that each Federal Aviation Administration (FAA) certificated mechanic or repairman maintaining an aircraft must be fully aware of his or her responsibility to provide the pilot with current and accurate information for the actual weight of the aircraft and the location of the CG. The pilot in command (PIC) is responsible for knowing the weight of the load, CG, maximum allowable weight, and CG limits of the aircraft. The weight and balance report must include an equipment list showing weights and moment arms of all required and optional items of equipment included in the certificate empty weight.

Weight and balance records used in accounting for and correcting the CG location are reliable for only limited periods of time. For this reason, periodic aircraft weighing is desirable. An aircraft should be reweighed and a new weight and balance record should be started after the aircraft has undergone extensive repair or major alteration, when the pilot reports unsatisfactory flight characteristics (e.g., nose or tail heaviness), and when recorded weight and balance data are suspected to be in error.

Repairs and alterations are major sources of weight change. The airframe and powerplant (A&P) FAA-certificated mechanic or repairman who is responsible for making any repair or alteration must:

1. Establish by computation that the authorized weight and CG limits as shown in the type certificate data sheet (TCDS) and aircraft specifications are not exceeded, and
2. Record the new empty weight center of gravity (EWCG) data in the current approved aircraft flight manual or issued operating limitations.

When an aircraft has undergone extensive repair or major alteration, it should be reweighed and a new weight and balance record started. The A&P FAA-certificated mechanic or repairman responsible for the work must provide the pilot with current and accurate aircraft weight information and location of the EWCG.

Equipment for Weighing

Weighing aircraft with accurately calibrated scales is the only sure method of obtaining an accurate empty weight and CG location. The two basic types of scales used to weigh aircraft are platform and load cell.

Platform scales *[Figure 3-1]* or ramp wheel scales *[Figure 3-2]* (usually a form or modified version of the platform scale) are low profi e, easy to handle, safe, and reliable. Tow or push the aircraft wheels or skids onto the scale pad at ground level. With one scale per wheel, each device should be capable of measuring up to at least 60,000 pounds since the weight on each wheel rarely exceeds this figure

Figure 3-1. *Platform scales.*

Load cell scales [Figure 3-3] are also a reliable means to weigh aircraft and are typically cheaper than the platform type.Using load cell scales allows for the aircraft to be set up and weighed in its level flight attitude. With this method, the aircraft is placed on jacks with electronic load cells placed between the jack and the jack pad on the aircraft. The aircraft is raised on the jacks until the wheels or skids are off the floor and the aircraft is in a level flight attitude. The weight measured by each load cell is indicated on the control panel. Jacking an aircraft off the ground from all load points can be an inconvenience, as well as a safety risk, which some operators would rather avoid by opting for more expensive—but simpler to use—platform equipment. In addition, weighing with platform scales typically takes only one-third of the time needed to weigh with load cells.

Figure 3-2. *Ramp scales.*

Figure 3-3. *Load cell scales.*

All scales for aviation use, manual or electronic, must be protected when stored or shipped, and they must be checked periodically for accuracy. The maximum recognized period between calibration checks is 12 months; however, this period may be reduced by an airworthiness authority dependent on the conditions of use. Scales in daily use may require a shorter interval and/or testing to determine the continued accuracy of the unit. Scales should be returned to the manufacturer for proper calibration and testing.

Preparation for Weighing

In general, weight procedures may vary with the aircraft and types of weight equipment employed. The weighing procedure contained in the manufacturer's maintenance manual should be followed for each particular aircraft. The major considerations in preparing an aircraft for weighing are described in the following paragraphs.

Scale Preparation

Mechanical and electronic scales shall be inspected prior to use and set to zero. This is done by adding and removing a weight, then rechecking for zero. This process should be repeated until a steady zero setting is obtained. The scales should be located in the same environment in which they are to be used and allowed to come up to temperature at least 2 hours prior to use. Scales should not be used in temperature extremes below 40 °F or above 100 °F unless the scale is specifically designed for use in those temperatures. Electronic scales are very sensitive and, if subjected to freezing temperatures, the liquid displays may be damaged beyond use.

Weigh Clean Aircraft Inside Hangar

The aircraft should be weighed inside a hangar where wind cannot blow over the surface and cause fluctuating or false scale readings. The aircraft should be clean inside and out, with special attention paid to the bilge area to ensure that no water or debris is trapped there. The outside of the aircraft should be as free as possible of all mud and dirt.

Equipment List

All of the required equipment must be properly installed, and there should be no equipment installed that is not included in the equipment list. If such equipment is installed, the weight and balance record must be corrected to indicate it.

Ballast

All required permanent ballasts must be properly secured in place. All temporary ballasts must be removed.

Standard Weights

Standard weights are established weights for numerous items involved in weight and balance computations. These weights should not be used if actual weights are available. Some of the standard weights are listed in *Figure 3-4*.

Weighing Point	Pounds per U.S. Gallon	
	32 °F	59 °F
AVGAS (Aviation Gasoline)	6.14	6.01
JET A & A-1	6.75	6.68
Water	8.35	8.33
Oil	7.50	7.43

Figure 3-4. *Standard fuels and weights with temperatures of 32 °F and 59 °F.*

Note the difference in weight as temperatures change. Although this change is a very small amount per gallon, it could end up in a significant total weight gain when dealing with large quantities of fluids, such as those found in commercial aircraft.

Draining the Fuel

Drain fuel from the tanks in the manner specified by the aircraft manufacturer. If there are no specific instructions, drain the fuel until the fuel quantity gauges read empty when the aircraft is in level-flight attitude. Any fuel remaining in the system is considered residual or unusable fuel and is part of the aircraft empty weight.

The amount of residual fuel and its arm are normally found in Note 1 in the section of the Type Certificate Data Sheets (TCDS), "Data pertaining to all Models." For additional fuel capacity information, see Chapter 2, Weight and Balance Theory.

If it is not feasible to drain the fuel, the tanks can be topped off to be sure of the quantity they contain and the aircraft weighed with full fuel. After weighing is complete, the weight of the fuel and its moment are subtracted from those of the aircraft as weighed. To correct the empty weight for the residual fuel, add its weight and moment.

When computing the weight of the fuel (e.g., a tank full of jet fuel), measure its specific gravity (sg) with a hydrometer and multiply it by 8.345 (the nominal weight of 1 gallon of pure water whose sg is 1.0). If the ambient temperature is high and the jet fuel in the tank is hot enough for its specific gravity to reach 0.81 rather than its nominal sg of 0.82, the fuel actually weighs 6.76 pounds per gallon rather than its normal weight of 6.84 pounds per gallon.

Oil

The empty weight for aircraft certificated under the Civilian Air Regulations (CAR) part 3 does not include the engine lubricating oil. The oil must either be drained before the aircraft is weighed, or its weight must be subtracted from the scale readings to determine the empty weight. To weigh an aircraft that does not include the engine lubricating oil as part of the empty weight, place it in level flight attitude, then open the drain valves and allow the oil to drain out. Any remaining is undrainable oil and is part of the empty weight. Aircraft certificated under Title 14 of the Code of Federal Regulations (14 CFR) parts 23 and 25 include full oil as part of the empty weight. If it is impractical to drain the oil, the reservoir can be filled to the specified level and the weight of the oil computed at 7.5 pounds per gallon. Then, its weight and moment are subtracted from the weight and moment of the aircraft as weighed. The amount and arm of the undrainable oil are found in Note 1 of the TCDS, and this must be added to the empty weight.

Other Fluids

The hydraulic fluid reservoir and all other reservoirs containing fluids required for normal operation of the aircraft should be full. Fluids not considered to be part of the empty weight of the aircraft are potable (drinkable) water, lavatory precharge water, and water for injection into the engines.

Configuration of the Aircraf

Consult the aircraft service manual regarding position of the landing gear shock struts and the control surfaces for weighing. When weighing a helicopter, the main rotor must be in its correct position.

Jacking the Aircraft

Aircraft are often weighed by rolling them onto ramps in which load cells are embedded. This eliminates the problems associated with jacking the aircraft off the ground. However, many aircraft are weighed by jacking the aircraft up and then lowering them onto scales or load cells.

Extra care must be used when raising an aircraft on jacks for weighing. If the aircraft has spring steel landing gear and it is jacked at the wheel, the landing gear will slide inward as the weight is taken off of the tire, and care must be taken to prevent the jack from tipping over.

For some aircraft, stress panels or plates must be installed before the aircraft is raised with wing jacks to distribute the weight over the jack pad. Be sure to follow the recommendations of the aircraft manufacturer in detail anytime an aircraft is jacked. When using two wing jacks, take special care to raise them simultaneously, keeping the aircraft so it does not slip off the jacks. As the jacks are raised, keep the safety collars screwed down against the jack cylinder to prevent the aircraft from tilting if one of the jacks should lose hydraulic pressure.

Leveling the Aircraft

When an aircraft is weighed, it must be in its level fligh attitude so that all of the components are at their correct distance from the datum. This attitude is determined by information in the TCDS. Some aircraft require a plumb line to be dropped from a specified location so that the point of the weight (the bob) hangs directly above an identifiable point. Others specify that a spirit level be placed across two leveling lugs, often special screws on the outside of the fuselage. Other aircraft call for a spirit level to be placed on the upper door sill.

Lateral level is not specified for all light aircraft, but provisions are normally made on helicopters for determining both longitudinal and lateral level. This may be done by built-in leveling indicators, or by a plumb bob that shows the conditions of both longitudinal and lateral level.

The actual adjustments to level the aircraft using load cells are made with the jacks. When weighing from the wheels, leveling is normally done by adjusting the air pressure in the nosewheel shock strut.

Safety Considerations

Special precautions must be taken when raising an aircraft on jacks.

1. Stress plates must be installed under the jack pads if the manufacturer specifies them
2. If anyone is required to be in the aircraft while it is being jacked, there must be no movement.
3. The jacks must be straight under the jack pads before beginning to raise the aircraft.
4. All jacks must be raised simultaneously and the safety devices are against the jack cylinder to prevent the aircraft tipping if any jack should lose pressure. Not all jacks have screw down collars, some use drop pins or friction locks.

Determining the CG

When the aircraft is in its level flight attitude, drop a plumb line from the datum and make a mark on the hangar floor below the tip of the bob. Draw a chalk line through this point parallel to the longitudinal axis of the aircraft.

Then, draw lateral lines between the actual weighing points for the main wheels, and make a mark along the longitudinal line at the weighing point for the nosewheel or the tailwheel. These lines and marks on the floor allow accurate measurements between the datum and the weighting points to determine their arms.

Determine the CG by adding the weight and moment of each weighing point to determine the total weight and total moment. Then, divide the total moment by the total weight to determine the CG relative to the datum. As an example of locating the CG with respect to the datum, which in this case is the firewall, consider the tricycle landing gear airplane as detailed in the *Figure 3-5* table and illustrated in *Figure 3-6*.

When the airplane is on the scales with the parking brakes

Weighing point	Scale reading (lb)	TARE weight (lb)	Net weight (lb)	Arm (in)	Moment (lb-in)	CG
Right side	846	16	830	46.0	38,180	
Left side	852	16	836	46.0	38,456	
Nose	348	8	340	−32.0	−10,880	
Total			2,006		65,756	32.8

Figure 3-5. *Locating the CG of an airplane relative to the datum.*

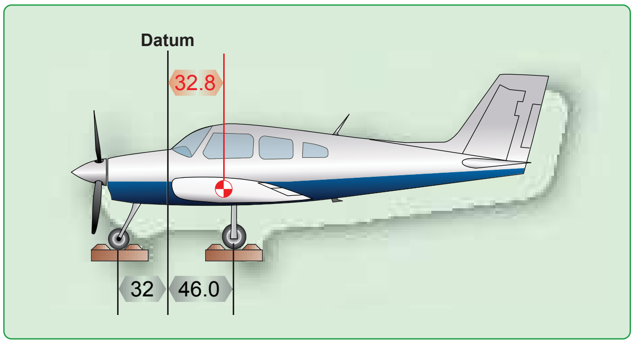


Figure 3-6. *The datum is located at the firewall.*

off, place chocks around the wheels to keep the airplane from rolling. Subtract the weight of the chocks, called tare weight, from the scale reading to determine the net weight at each weighing point. Multiply each net weight by its arm to determine its moment, and then determine the total weight and total moment. The CG is determined by dividing the total

$$CG = \frac{\text{Total moment}}{\text{Total weight}}$$
$$= \frac{65{,}756}{2{,}006}$$
$$= 32.8 \text{ inches behind the datum}$$

Figure 3-7. *Determining the CG.*

moment by the total weight. *[Figure 3-7]*

The airplane illustrated in *Figures 3-5* and *3-6* has a net weight of 2,006 pounds, and its CG is 32.8 inches behind the datum.

EWCG Formulas

A chart such as the one in *Figure 3-5* helps the pilot visualize the weights, arms, and moments when solving an EWCG problem, but it is quicker to determine the EWCG by using formulas and an electronic calculator. The use of a calculator for solving these problems is described in Chapter 8, Use of Computers in Weight and Balance Computations.

There are four possible conditions and their formulas that relate the location of CG to the datum. Notice that the formula for each condition first determines the moment of the nosewheel or tailwheel and then divides it by the total weight of the airplane. The arm thus determined is then added to or subtracted from the distance between the main wheels and the datum, distance D.

Datum Forward of the Airplane—Nosewheel Landing Gear

The datum of the airplane in *Figure 3-8* is 100 inches forward of the leading edge of the wing root or 128 inches forward

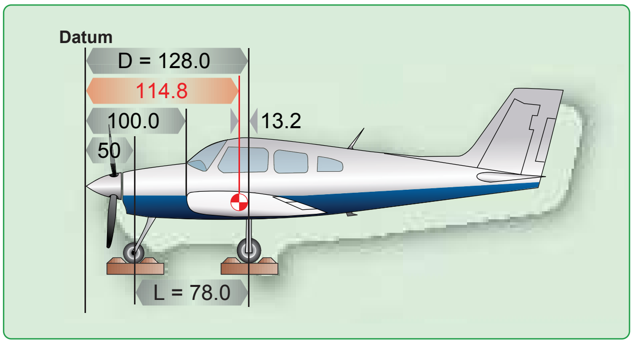


Figure 3-8. *The datum is 100 inches forward of the wing root leading edge.*

of the main-wheel weighing points. This is distance (D). The weight of the nosewheel (F) is 340 pounds, and the distance between main wheels and nosewheel (L) is 78 inches. The total weight of the airplane (W) is 2,006 pounds. Determine

$$CG = D - \left(\frac{F \times L}{W}\right)$$
$$= 128 - \left(\frac{340 \times 78}{2{,}006}\right)$$
$$= 114.8$$

Figure 3-9. *Determining the CG with datum forward of an airplane with nosewheel landing gear.*

the CG by using the formula in *Figure 3-9*.

The CG is 114.8 inches aft of the datum. This is 13.2 inches forward of the main-wheel weighing points, which proves the location of the datum has no effect on the location of the CG if all measurements are made from the same location.

Datum Aft of the Main Wheels—Nosewheel Landing Gear

The datum of some aircraft may be located aft of the main wheels. The airplane in this example is the same one just discussed, but the datum is at the intersection of the trailing edge of the wing with the fuselage. The distance (D) between the datum of the airplane in *Figure 3-10* and the main-wheel

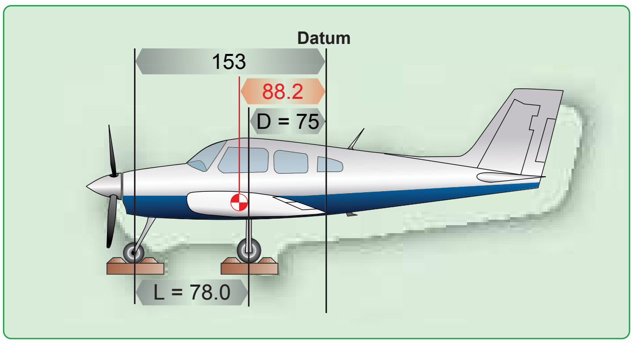


Figure 3-10. *The datum is aft of the main wheels at the wing trailing edge.*

weighing points is 75 inches, the weight of the nosewheel (F) is 340 pounds, and the distance between main wheels and nosewheel (L) is 78 inches. The total net weight of the airplane (W) is 2,006 pounds.

The location of the CG may be determined by using the formula in *Figure 3-11*.

$$CG = -\left(D + \frac{F \times L}{W}\right)$$
$$= -\left(75 + \frac{340 \times 78}{2{,}006}\right)$$
$$= -88.2$$

Figure 3-11. *Determining the CG with datum aft of the main wheels of an airplane with nosewheel landing gear.*

The CG location is a negative value, which means it is 88.2 inches forward of the datum. This places it 13.2 inches forward of the main wheels, exactly the same location as when it was measured from other datum locations.

Location of Datum

The location of the datum is not important, but all measurements must be made from the same location.

Datum Forward of the Main Wheels—Tailwheel Landing Gear

Locating the CG of a tailwheel airplane is done in the same way as locating it for a nosewheel airplane except the formula is $\left(\frac{R \times L}{W}\right)$

The distance (D) between the datum of the airplane in *Figure 3-12* and the main-gear weighing points is 7.5 inches, the weight of the tailwheel (R) is 67 pounds, and the distance (L) between the main-wheel and the tailwheel weighing points is 222 inches. The total weight of the airplane (W) is 1,218 pounds. Determine the CG by using the formula in *Figure 3-13*.

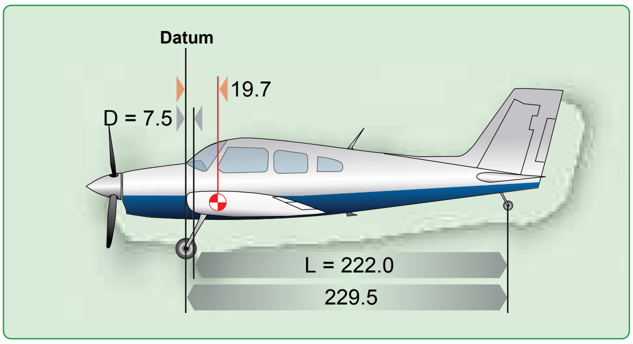


Figure 3-12. *The datum of this tailwheel airplane is the wing root leading edge.*

$$CG = D + \left(\frac{R \times L}{W}\right)$$
$$= 7.5 + \left(\frac{67 \times 222}{1{,}218}\right)$$
$$= 19.7$$

Figure 3-13. *Determining the CG with datum forward of the main wheels in an airplane with tailwheel landing gear.*

The CG is 19.7 inches behind the datum.

Datum Aft of the Main Wheels—Tailwheel Landing Gear

The datum of the airplane in *Figure 3-14* is located at the intersection of the wing root trailing edge and the fuselage. This places the arm of the main gear (D) at –80 inches. The net weight of the tailwheel (R) is 67 pounds, the distance between the main wheels and the tailwheel (L) is 222 inches, and the total net weight (W) of the airplane is 1,218 pounds. Since the datum is aft of the main wheels, use the formula found in *Figure 3-15*.

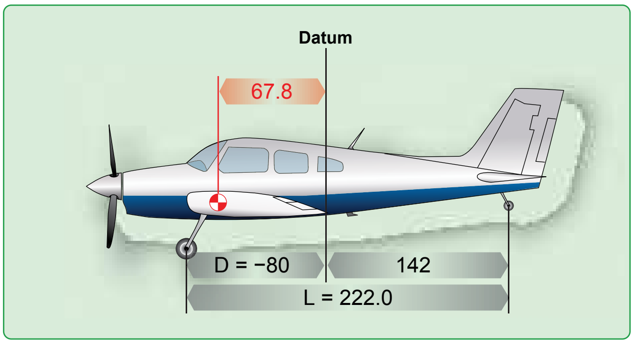


Figure 3-14. *The datum is aft of the main wheels, at the intersection of the wing trailing edge and the fuselage.*

$$CG = -D + \left(\frac{R \times L}{W}\right)$$
$$= -80 + \left(\frac{67 \times 222}{1{,}218}\right)$$
$$= -67.8$$

Figure 3-16. *Determining the CG with datum aft of the main wheels in an airplane with tailwheel landing gear.*

The CG is 67.8 inches forward of the datum or 12.2 inches aft of the main-gear weighing points. The CG is in exactly the same location relative to the main wheels, regardless of where the datum is located.

Center of Gravity (CG) and Mean Aerodynamic Chord (MAC)

Center of Gravity (CG)

In addition to overloading or drastically reducing the aircraft's weight, the distribution of weight is also a concern. When aircraft equipment is changed, the person making the equipment change must make an entry on the equipment list indicating items added, removed, or relocated; the date of the change; and the person's name and certification number in the aircraft's maintenance records.

For the purpose of weight and balance computations, the CG of an airplane is an imaginary point about which the nose-heavy (–) moments and tail-heavy (+) moments are exactly equal in magnitude. If suspended from the CG point, the aircraft would have no tendency to rotate nose up or nose down. The CG of the loaded aircraft can range fore and aft within certain limits that are determined during the fl ght test for type certific tion. These limits are the most forward- and rearward-loaded CG positions at which the aircraft meets the performance and flight characteristics required by the FAA.

Any loading that places the CG outside the limits for a particular aircraft seriously impairs the pilot's ability to control the aircraft. For example, it is more difficult to take off and gain altitude in a nose-heavy aircraft, and the aircraft tends to drop its nose when the pilot reduces throttle. It also requires a higher speed to land safely. A tail-heavy aircraft is more susceptible to stalling at low speed, which is a concern during the landing approach.

On small airplanes and on all helicopters, the CG location is identified as being a specific number of inches from the datum. The CG range is identified in the same way. On larger airplanes, from private business jets to large jumbo jets, the CG and its range are typically identified in relation to the width of the wing.

Mean Aerodynamic Chord (MAC)

The width of the wing, or straight-line distance from the leading edge to the trailing edge, on an airplane is known as the chord. If the leading edge and the trailing edge of a wing are parallel, the chord is equal at all points along the entire length of the wing. The average length of the chord, or MAC, of a tapered wing is more complicated to define. The MAC, as seen in *Figure 3-16*, is the chord of an imaginary airfoil that has the same aerodynamic characteristics as the actual airfoil. You can also think of it as the chord drawn through the geographic center of the plan area of the wing.

Usually listed in the aircraft's TCDS when it is required for

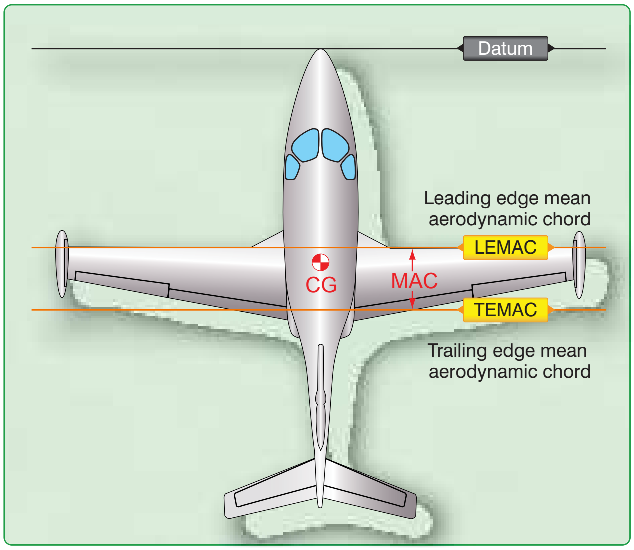


Figure 3-16. *The MAC is the chord drawn through the geographic center of the plan area of the wing.*

weight and balance computations, the MAC is established by the manufacturer, defining its leading edge (LEMAC) and trailing edge (TEMAC) in terms of inches from the datum. *[Figure 3-16]* The CG location and various limits are then expressed in percentage of the chord or percent MAC. In order to relate the percent MAC to the datum, all weight and balance information includes two items: the MAC length in inches and the location of the LEMAC in inches from the datum. For the purpose of simplicity, most light-aircraft manufacturers express the CG range in inches from the datum; transport-category aircraft CGs are expressed in percent MAC.

The relative positions of the CG and the aerodynamic center of lift of the wing have critical effects on the flight characteristics of the aircraft. Consequently, relating the CG location to the chord of the wing is convenient from a design and operations standpoint. Normally, an aircraft has acceptable fl ght characteristics if the CG is located somewhere near the 25 percent average chord point. This means the CG is located one-fourth of the distance back from the LEMAC to the TEMAC. Such a location places the CG forward of the aerodynamic center for most airfoils.

The weight and balance data of the airplane in *Figure 3-17* states that the MAC is from stations 144 to 206 and the CG is located at station 161.

MAC = TEMAC – LEMAC

MAC = 206" – 144"

MAC = 62"

Figure 3-17. *Large aircraft weight and balance calculation diagram.*

CG = 161"

In order to find the percent MAC, firs determine the distance of the CG from LEMAC.

CG – LEMAC = Distance from LEMAC

161" – 144" = 17"

The location of the CG expressed in percent MAC is

$$\text{CG inches \% MAC} = \frac{\text{Distance aft of LEMAC} \times 100}{\text{MAC}}$$
$$= \frac{17 \times 100}{62}$$
$$= 27.4$$

Figure 3-18. *Formula for determining the CG expressed in percent MAC.*

determined using the formula found in *Figure 3-18*. The CG of the airplane is located at 27.4 percent MAC.

It is sometimes necessary to determine the location of the CG in inches from the datum when its location in percent MAC is known.

The CG of the airplane is located at 27.4 percent MAC.

MAC = 206 – 144 = 62

LEMAC = station 144

$$\text{CG inches from datum} = \text{LEMAC} + \frac{\text{MAC} \times \text{CG \% MAC}}{100}$$
$$= 144 + \frac{62 \times 27.4}{100}$$
$$= 160.9$$

Figure 3-19. *Formula for determining the CG in inches from the datum.*

Determine the location of the CG in inches from the datum by using the formula found in *Figure 3-19*.

The CG of this airplane is located at station 160.9 inches aft of the datum. It is important for longitudinal stability that the CG be located ahead of the center of lift of a wing. Since the center of lift is expressed as percent MAC, the location of the CG is expressed in the same terms.